Centre for Research and Analysis of Migration

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CDP No 09/10

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Non-Technical Abstract

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Keywords: Brain drain, Development, Multiple equilibria, Coordination failure.

JEL Classification: F22, O11, O15, C62.

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David de la Croix[1] Frédéric Docquier[2]

March 2010

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*Thanks are due to the Trade Team - Development Research Group of the World Bank for its financial support (World Bank contract PO. 7620076 - UPI 269656), and to Sara Salomone for assistance with various aspects of the paper. The authors acknowledge financial support from the ARC conventions on "Geographical mobility of factors" and "Sustainability" , the PAI convention "Glonomics" and from the Marie-Curie research and training network TOM. We thank Fabio Mariani and participants to seminars in Luxembourg, Le Mans, Nantes, and ISI New Delhi for comments on an earlier draft.

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1 Introduction

Many observers and scholars have long considered the brain drain as a curse for origin countries in general, and for the developing world in particular. Although the new literature is less pessimistic, and shows that positive spillovers can be induced by high-skill emigration, it is fairly obvious that the brain drain affects the human capital accumulation and economic performance of sending countries. It is also largely recognized that lack of economic growth and rampant poverty (going hand in hand with discrimination, political repression and lack of freedoms) is what motivates people to flee their own country.

The interdependencies between high-skill emigration and poverty in developing countries are key to understanding the process of development. They can be the source of vicious and virtuous circles linked to strategic complementarities in individual migration decisions. Indeed, when a significant brain drain movement is initiated, it may have damaging effects on the economy and induce other waves of high-skill emigration. On the contrary, when a significant return movement operates, it gives incentives to other waves of emigrants to return home.

History has shown that massive and rapid outflows of high-skill people can generate economic damage which is hard to reverse. An interesting case is that of Iran, where pre-revolutionary economic development was rapid, although unevenly distributed among Iranians. The Iranian brain drain (Torbat, 2002) started with the 1978-1979 revolution and was exacerbated in the early 1980s by the war with Iraq and the decision of the government to reform Iran's higher education system. The trend continued afterwards and is seen by many observers as one of the most important exoduses of talented academics, students, and researchers. The pace of growth slowed dramatically after the revolution and Iran is still a lower-middle income economy today. Since 2002, Iran's parliament has tried to reverse its brain drain but returns are still sporadic.

A more recent example is the former Soviet states. Many scientists and academics went abroad after independence. Russian and Moldovian trade unions report that between half a million and a million scientists and professionals have left the country since 1991. This has worsened the economic situation and working conditions at origin; hence, almost none of the brain drain emigrants have returned.

Breaking such vicious circles requires major reforms (democratic or dictatorial[1]). In the

[1] In the early sixties, the East German government opted for an authoritarian policy. After World War II, the Potsdam agreement determined the borders of Germany and Berlin. After that, and until 1960, East Germany suffered a huge brain drain to West Germany and a substantial inflow of Western students who benefitted from the free Eastern education system before returning to the West. By 1960, tens of thousands

1980s, the return of educated elites and high-skill workers played a crucial role in Taiwan's economic takeoff, starting with the development of the information industry in Hsinchu. The Irish case is another nice illustration of the vicious and virtuous effects of high-skill mobility. On the one hand, mass emigration of university and college graduates was observed in the 1980s. This brain drain sucked the marrow out of Ireland's social and economic development. On the other hand, the major fiscal reforms embraced after 1987 attracted foreign companies and investments. Since the late 1990s, there has been a huge return migration, which contributed to the "Irish miracle" (Barrett, 2001).

The question addressed in this paper is: can a "high brain drain/high poverty"situation be the result of a coordination failure, or is a brain drain an inevitable corollary of poverty, just making the situation slightly worse? For each developing country, the data set compiled by Docquier, Lowell and Marfouk (2009) gives precise information on the human capital level of residents and emigrants. In 2000, the average skill-ratio (i.e. ratio of tertiary to non-tertiary educated workers) of high-income countries was 0.243 (with values above 1 in the US and Canada). In the same year, 23 developing countries would have exhibited a skill-ratio above 0.243 if all their high-skill emigrants returned home. Saint Kitts and Nevis (0.866) would be close to the US and Canada; Grenada (0.611) and Dominica (0.471) and other small states would be close to Australia (0.514). Other larger countries such as the Philippines (0.333), Peru (0.309), Jamaica (0.279) and Latvia (0.271) would have more human capital than many Western European countries. If such returns were large enough to generate a rapid takeoff and eradicate incentives to emigrate, brain drain and poverty could be seen as resulting from a coordination failure. If not, the brain drain just worsens the situation. The goal of this paper is to address this issue using an integrated model of human capital accumulation, high-skill emigration and economic performance.

Surprisingly, the bi-directional causal link between emigration and poverty has only been investigated unidirectionally in the recent brain-drain literature. Many empirical studies focusing on the determinants of migration flows have disregarded the composition of these flows. However, a few recent contributions have taken advantage of new databases on international migration by education level to investigate the determinants of the brain drain and the skill composition of emigration flows. Docquier, Lohest and Marfouk (2007) showed that the brain drain increases with political instability and the degree of fractionalization, and decreases with the level of development at origin. Grogger and Hanson (2008) found that a

workers were moving from East to West every month, including about 40,000 with academic or professional qualifications trained in East Germany. In the summer of 1961, the city of Berlin was walled off. Stopping the vicious circle of brain drain and impoverishment (and the considerable abuse of the East German education system) were the main economic reasons for building the Berlin wall.

simple model of income maximization could account for positive selection (higher emigration rates for the skilled) and positive sorting (positive effect of wage differentials on the proportion of skilled workers in bilateral migration). Rosenzweig (2007, 2008) used micro-data to demonstrate that there are larger per-capita numbers of foreign students in the United States from lower skill-price countries than from high skill-price countries, and host countries with higher skill prices attract more foreign students. These studies clearly reveal that the size and structure of international migration flows are endogenous and depend on the economic characteristics of source and host countries. In the empirical literature, these characteristics are usually treated as exogenous (or instrumented).

Another literature focuses on the consequences of the brain drain on the welfare of those left behind. The first welfare theorem suggests that labor mobility increases the total amount of welfare at the world level. It is Pareto-improving if those gains can be appropriately redistributed among all parties concerned. When redistribution is impossible or costly, some parties can be adversely affected although the size of the pie is enlarged. This argument can be decisive for those left behind if there are strong complementarities between skilled and unskilled workers on the labor market, or if the fiscal cost of education is large and totally supported by residents at origin. Bhagwati and Hamada (1974) and McCullock and Yellen (1975, 1977) were among the first to stress the negative impact of the brain drain for developing countries. The brain drain was seen as a zero sum game with the rich countries getting richer and the poor countries getting poorer. Later, relying on the existence of externalities linked to human capital, the endogenous growth framework offered an appropriate environment to demonstrate that any loss of human capital can be detrimental for remaining households (e.g., Miyagiwa, 1991, Haque and Kim, 1995). We will refer to this view as the "traditional" brain drain literature. However, a newer literature (Mountford, 1997; Stark et al., 1998; and Beine et al., 2001) suggests that the emigration of skilled workers can increase sending-country educational investment and induce other positive feedback effects. In particular, the prospect of emigration to countries where skills are rewarded more generously can lead not only to increased investment in skills before migration (*ex ante*), but also to a larger well educated domestic population after migration (*ex post*).[2] We will refer to this view as the "brain gain" literature. A problem with these "traditional" and "brain gain" models is that they usually ignore the endogeneity of the emigration probability.

In this paper, we will build bridges between these two strands of literature and develop a richer model allowing for coordination failures. We first consider the traditional view and disregard "brain gain" mechanisms. The reduced form of our model can be summarized

[2] Beine et al. (2008) found that a brain drain stimulates human capital formation before migration, and estimated the net effect of the brain drain on human capital accumulation for each developing country.

by two equations, one endogenizing the level of development and the other endogenizing human capital accumulation. Under certain conditions, the system generates indeterminacy and multiple long-run equilibria. Multiplicity implies that two countries sharing particular characteristics may end up on different paths, a good one with low poverty and low brain drain, or a bad one with high poverty and high brain drain. The properties of the equilibria need not be identical across nations. They depend on the exogenous characteristics of nations and policies. For example, small countries geographically or culturally close to the rich world are likely to exhibit stronger elasticities of migration to the economic environment than large, landlocked and remote countries.

We calibrate and simulate our model for 147 developing countries. Our numerical experiments reveal that 22 countries (including 20 small states with less than 2 million inhabitants) are suffering from coordination failure. In these countries, a positive shock or better expectations could generate a virtuous circle of rapid returns and economic prosperity. Other small states and larger states are on the good paths, including both Russia and Iran which lost large absolute numbers of tertiary educated people (475,095 for Russia and 315,640 for Iran). Given their size, these numbers represent relatively small proportions of their educated labor force (2.4 percent in Russia and 14.7 in Iran). These proportions are too low to result from coordination problems. For most large countries, the bad long-run equilibrium is irrelevant, as it would entail one–hundred-percent brain drain. Nevertheless, 27 of them exhibit a non-trivial bad equilibrium with reasonably high brain drain and poverty; these 27 countries thus risk a radical worsening of their economic performance. These results are fairly robust to our identification strategy and to the inclusion of "brain gain" mechanisms.

The paper is organized as follows. Section 2 describes the theoretical framework and derives the conditions under which multiplicity is obtained. Our benchmark model follows the "traditional" literature on brain drain and development, *i.e.* considers the brain drain as unambiguously detrimental for human capital accumulation. In Section 3, we use macrodata to calibrate the benchmark model on developing countries and to identify country-specific characteristics. This allows us to characterize the type of equilibrium observed in each developing country. In Section 4, we analyze the robustness of our results to identifying assumptions and account for the recent "brain gain" literature. Finally, we present our conclusions in Section 5.

2 Theory

Our model depicts a set of developing economy with endogenous technology, high-skill emigration and human-capital accumulation. Time is discrete. One period is meant to describe the active life of one generation. Each developing country is characterized by a linear production function with two perfectly substitutable inputs, high-skill and low-skill labor (H_t and L_t), and an endogenous productivity factor λ_t:

$$Y_t = \lambda_t \left(\overline{\omega} L_t + H_t \right) \tag{1}$$

where $\overline{\omega} < 1$ is the average productivity of low-skill workers relative to high-skill workers. Hence, high-skill workers' income is equal to λ_t whereas low-skill workers earn $\overline{\omega}\lambda_t$. The assumption of perfect substitutability of the two types of labor is made for mathematical simplicity. It obviously implies that the skill premium is exogenous. This is in line with Rosenzweig (2007, 2008) who shows that cross-country differences in skill prices are much more affected by differences in base wages (λ_t) than by differences in returns to skills ($1/\overline{\omega}$). In addition, many empirical studies advocate using a high elasticity of substitution to match data on the skill premium in developing countries.[3]

We consider a Lucas-type technological externality (see Lucas, 1988) and assume that the scale productivity factor is a concave function of the skill-ratio in the resident labor force. Hence, we have

$$\lambda_t = A\gamma^t k_t^\alpha \qquad \text{with } k_t \equiv \frac{H_t}{L_t} \tag{2}$$

where A is a country fixed effect, γ^t is a time trend which is common to all developing and developed countries ($\gamma > 1$), and $\alpha \in (0,1)$ is the elasticity of productivity to the skill-ratio.

Preferences are represented by an indirect utility function assumed to be logarithmic in income. Low-skill individuals are immobile across countries whereas high-skill individuals have the choice between staying in their country or emigrating to a richer industrialized country before entering the labor market. Migration is permanent and we disregard the links between migrants and their origin country (such as remittances and diaspora externalities). Productivity or income at destination is exogenous and denoted by $\overline{\lambda}_t = \bar{A}\gamma^t$ with $\bar{A} > 0$. We do not endogenize $\bar{A}$ as a function of the skill-ratio at destination, implicitly assuming that high-skill immigration from each developing country is too small to affect productivity. Hence, our model is only relevant to the analysis of developing countries.

[3] Ottaviano and Peri (2008) use a range of estimates between 1.5 and 3 whereas Angrist (1995) recommends a value above 2 to explain the trends in the college premium on the Palestinian labor market.

Migration induces heterogenous moving costs which must be subtracted from the utility level. We denote the migration cost if individual i by $\tilde{\varepsilon}_i$. Hence, migration is optimal for individual i if and only if

$$\ln \bar{A} - \tilde{\varepsilon}_i \geq \ln A + \alpha \ln k_t.$$

At time t, all individuals with migration costs below a critical value ε_t find it optimal to emigrate. The critical value is given by

$$\varepsilon_t = \ln \bar{A} - \ln A - \alpha \ln k_t \tag{3}$$

The threshold ε_t is decreasing with the skill-ratio k_t and characterizes the income differential (in logs) with high-income destinations. At the margin, the migration costs for the individual who is indifferent between migrating or staying is equal to the income differential. It can reasonably be used as an index of poverty (or underdevelopment) of the country.

Migration costs are distributed according to a cumulative distribution function $G(\tilde{\varepsilon})$ with location parameter m and dispersion parameter b. Hence, $G_t = G(\varepsilon_t)$ measures the proportion of high-skill emigrants at time t, i.e. the rate of brain drain. We impose Assumption 1 on $G(\tilde{\varepsilon})$.

Assumption 1 *The distribution function of migration costs satisfies*[4]

$$G'(x) = o\left(\exp\left(-x/\alpha\right)\right) whenx \rightarrow +\infty$$

As will be evident later, Assumption 1 is a sufficient condition to obtain multiplicity of equilibria and coordination failures. It holds when $G'(\tilde{\varepsilon})$ goes to 0 much faster than $\exp\left(-\tilde{\varepsilon}/\alpha\right)$ as $\tilde{\varepsilon}$ goes to infinity. This implies that the migration choice is sensitive enough to the wage differential when this differential is large.

Assumption 1 always holds when the cumulative distribution function $G(\tilde{\varepsilon})$ reaches one for a value of $x \in \mathbb{R}$. It is also always satisfied if $G(\tilde{\varepsilon})$ is a normal distribution with positive mean, or if $G(\tilde{\varepsilon})$ is a Gumbel distribution with positive location. If $G(\tilde{\varepsilon})$ is a logistic distribution, Assumption 1 holds provided that b, the scale of the distribution, is larger than α.

At this stage, it is useful to distinguish k_t, the skill-ratio in the *ex post* (or after-migration) resident labor force and z_t, the skill-ratio in the *ex ante* (or before-migration) native labor

[4] *o(.)* means little-o of (Landau notation).

force. Since only educated workers migrate at a rate $G(\varepsilon_t)$, we obviously have

$$k_t = z_t \left[1 - G(\varepsilon_t)\right] \tag{4}$$

The dynamics are governed by human capital accumulation. For simplicity, it is assumed that high-skill workers educate all their children whereas low-skill workers only educate a fraction $q \in (0, 1)$ of them. q is assumed to be exogenous. Denoting the skilled population by Z^s and the low-skill population by Z^u, their dynamics are given by

$$\begin{aligned} Z^s_{t+1} &= n^s Z^s_t \left[1 - G(\varepsilon_t)\right] + q\, n^u\, Z^u_t \\ Z^u_{t+1} &= (1 - q)\, n^u\, Z^u_t \end{aligned}$$

Where n^s and n^u measure the number of children in high-skill and low-skill households. Denoting by $n = n^s/n^u$ the relative number of children in high-skill households (compared to the number in low-skill households), we have

$$z_{t+1} = Z^s_{t+1}/Z^u_{t+1} = \frac{1 - G(\varepsilon_t)}{1 - q}\, n\, z_t + \frac{q}{1 - q} \tag{5}$$

Our model is made up of Equations (1) to (5). In these equations, we consider that parameters $\bar{A} > 0$, $\alpha \in (0, 1)$ and $n \in (0, 1)$ are identical across developing countries. The other exogenous parameters A, q, m and b are country-specific. Hence, a developing country can be identified as follows.

Definition 1 *A developing country is a quadruple $\Omega = \{A, q, m, b\}$representing the technological fixed effect ($A > 0$), the fraction of educated children in low-skill households ($q \in (0, 1)$), the location and the scale parameters of the distribution of migration costs ($m \in \mathbb{R}$, $b > 0$).*

The parameters and country characteristics determine the level and the time path of the two main endogenous variables, the index of poverty ε_t and the *ex ante* skill-ratio z_t. Indeed, when trajectories for ε_t and z_t are known, it is straightforward to compute the trajectories of the other endogenous variables (λ_t, Y_t, k_t). In other words, the system of Equations (1) to (5) can easily be reduced to a two-variable system.

Definition 2 *Given an initial skill-ratio in the native labor force $\bar{z}_0 > 0$, an inter-temporal equilibrium with migration is a vector of the skill-ratios $\{z_t\}_{t \geq 0} \in \mathbb{R}^\infty_+$ and a vector of poverty* *indexes* $\{\varepsilon_t\}_{t\geq 0} \in \mathbb{R}^\infty$ *such that* $z_0 = \bar{z}_0$ *and* $\forall t \geq 0$*:*

$$\varepsilon_t = \ln \bar{A} - \ln A\left[(1-G(\varepsilon_t))\, z_t\right]^\alpha \equiv f(\varepsilon_t, z_t), \tag{6}$$

$$z_{t+1} = \frac{q}{1-q} + \frac{1-G(\varepsilon_t)}{1-q} n z_t \equiv h(\varepsilon_t, z_t). \tag{7}$$

Equation (6) is a static incentive compatibility condition. For a given *ex ante* skill-ratio z_t, it characterizes the combination(s) of poverty index ε_t and high-skill emigration rate $G(\varepsilon_t)$ compatible with the technology level and households' emigration decisions at time t. Equation (7) is dynamic and characterizes human-capital accumulation. For a given *ex ante* skill-ratio and poverty index at time t, it gives the *ex ante* skill-ratio at time $t+1$.

We have the following result:

Lemma 1 *Under Assumption 1, there exists a threshold* $\hat{z}$ *such that, in equilibrium,* $z_t > \hat{z}$ $\forall t \geq 0$*.*

Proof. We prove the lemma using a *reductio ad absurdum argument. Suppose we have an equilibrium with, at some date* s*,* $z_s < \hat{z}$*. We will show that there can be no* ε_s *satisfying* $\varepsilon_s - f(\varepsilon_s, z_s) = 0$*, that is, Equation (6). Solving (6) for* z_s *we obtain*

$$z_s = \Phi \frac{\exp(-\varepsilon_s/\alpha)}{1-G(\varepsilon_s)} \equiv \phi(\varepsilon_s) \quad \textit{with} \quad \Phi = \left(\frac{\bar{A}}{A}\right)^{1/\alpha}.$$

The function $\phi(\varepsilon)$ *is continuous. Its limit when* $\varepsilon \to -\infty$ *is equal to* $+\infty$*. Under Assumption 1, its limit when* $\varepsilon \to +\infty$ *is equal to* $+\infty$*. It therefore has a global minimum at some* $\hat{\varepsilon}$*. This global minimum should satisfy:*

$$\phi'(\hat{\varepsilon}) = 0 \Leftrightarrow 1 - G(\hat{\varepsilon}) - \alpha G'(\hat{\varepsilon}) = 0$$

Let us define $\hat{z} = \phi(\hat{\varepsilon})$*. There is no* $\varepsilon \in \mathbb{R}$ *such that* $\phi(\varepsilon) < \hat{z}$*. As a consequence there is no* $\varepsilon \in \mathbb{R}$ *solving (6) for* $z < \hat{z}$*. Hence, when* $z_s < \hat{z}$*, (6) could not hold and this cannot be an equilibrium.* ■

We now introduce a second assumption, which is in no way crucial for the following results, but greatly simplifies the analysis.

Assumption 2 *The distribution function of migration costs is such that there is a unique* ε *satisfying*

$$1 - G(\varepsilon) - \alpha G'(\varepsilon) = 0.$$

This implies that:

Lemma 2 *Under Assumptions 1 and 2, for any level $z_t > \hat{z}$ there exist two values of ε_t, $s^+(z_t) > s^-(z_t)$, such that the incentive constraint $\varepsilon_t = f(\varepsilon_t, z_t)$ holds.*

Proof. Consider the function $z = \phi(\varepsilon) \Leftrightarrow \varepsilon - f(\varepsilon, z) = 0$. We have seen in the proof above that it goes from $+\infty$ to $+\infty$ as ε goes from $-\infty$ to $+\infty$, and has a global minimum at the point $(\hat{\varepsilon}, \hat{z})$. Assumption 2 implies that this function changes slope only once, at its minimum. As a consequence, for any $z_t > \hat{z}$, there are two values of ε_t such that $\varepsilon_t - f(\varepsilon_t, z_t) = 0$. Let us denote these two solutions $s^+(z_t) > s^-(z_t)$. ■

The solution $s^+(z_t)$ corresponds to a high poverty index and high brain drain: the *ex post* skill ratio k_t is well below the *ex ante* level z_t and the productivity level is low. Solution $s^-(z_t)$ corresponds to a low poverty index and low brain drain: the *ex post* skill ratio k_t is closer to the *ex ante* level z_t and the productivity level is higher. At each t, there are therefore two values of z_{t+1} compatible with Equations (6) and (7). The dynamics can be written as:

$$z_{t+1} = \begin{cases} h(s^+(z_t), z_t) \\ \quad\text{or} \\ h(s^-(z_t), z_t) \end{cases} \tag{8}$$

If these two values are above $\hat{z}$, we can compute four values of z_{t+2} using Equations (6) and (7), eight values of z_{t+3} and so on. Hence there may be an infinite number of equilibria, starting from the initial condition $\bar{z}_0$.

$$\begin{array}{ccccccc}
 & & & & & \nearrow & \cdots \\
 & & & & h(s^-(z_1^+), z_1^+) & \longrightarrow & \cdots \\
 & & & \nearrow & & & \\
 & & z_1^+ = h(s^-(\bar{z}_0), \bar{z}_0) & \longrightarrow & h(s^+(z_1^+), z_1^+) & \longrightarrow & \cdots \\
 & \nearrow & & & & \searrow & \cdots \\
\bar{z}_0 & & & & & & \\
 & \searrow & & & & \nearrow & \cdots \\
 & & z_1^- = h(s^+(\bar{z}_0), \bar{z}_0) & \longrightarrow & h(s^-(z_1^-), z_1^-) & \longrightarrow & \cdots \\
 & & & \searrow & & & \\
 & & & & h(s^+(z_1^-), z_1^-) & \longrightarrow & \cdots \\
 & & & & & \searrow & \cdots
\end{array}$$

In order to describe the possible long-run outcomes more precisely, we list here some properties of the two functions $h(s^+(z_t), z_t)$ and $h(s^-(z_t), z_t)$:

- $h(s^+(\hat{z}), \hat{z}) = h(s^-(\hat{z}), \hat{z}) = h(\hat{\varepsilon}, \hat{z})$;
- since $\phi'_\varepsilon < 0$ for $\varepsilon < \hat{\varepsilon}$, and $s^-(z_t)$ is a decreasing function, the function $h(s^-(z_t), z_t)$ is increasing in z_t;
- since $s^+(z_t) > s^-(z_t)$, $h(s^-(z_t), z_t) > h(s^+(z_t), z_t)$;
- when z tends to infinity, the function $h(s^-(z_t), z_t)$ tends to the oblique asymptote obtained under $G(\varepsilon) = 0$:
$$\frac{q}{1-q} + \frac{n}{1-q}z;$$
- when z tends to infinity, the function $h(s^+(z_t), z_t)$ tends to the horizontal asymptote obtained under $G(\varepsilon) = 1$:
$$\frac{q}{1-q}.$$

Figure 1 represents a dynamic correspondence which satisfies the properties derived above.

The following proposition summarizes the conditions for the existence of an equilibrium.

Proposition 1 *Under Assumptions 1 and 2 an inter-temporal equilibrium exists under the conditions:*

When $h(\hat{\varepsilon}, \hat{z}) > \hat{z}$, an equilibrium exists if $z_0 > \hat{z}$.

When $h(\hat{\varepsilon}, \hat{z}) < \hat{z}$,

- *no equilibrium exists if $h(s^-(z), z) < z$ for all $z > 0$.*
- *if there exists $\tilde{z} > 0$ such that $h(s^-(\tilde{z}), \tilde{z}) < \tilde{z}$ and if $\bar{z}_0 \geq \underline{z}$, where $\underline{z}$ is the smallest steady state of the dynamics $z_{t+1} = h(s^-(z_t), z_t)$, an equilibrium exists.*

Proof. When $h(\hat{\varepsilon}, \hat{z}) > \hat{z}$, $z_0 > \hat{z}$ ensures that there is at least one inter-temporal equilibrium satisfying the monotone dynamics $z_{t+1} = h(s^-(z_t), z_t)$.

When $h(\hat{\varepsilon}, \hat{z}) < \hat{z}$, if $h(s^-(z), z) < z$ for all $z > 0$, the function $h(s^-(z_t), z_t) < z_t$ lies below the forty-five degree line for all z_t, all the possible dynamics starting from $\bar{z}_0$ are decreasing, and there will inevitably be some date T at which $z_t < \hat{z}$. Hence, no inter-temporal equilibrium exists.

When $h(\hat{\varepsilon}, \hat{z}) < \hat{z}$, if there exists $\tilde{z} > 0$ such that $h(s^-(\tilde{z}), \tilde{z}) < \tilde{z}$, the function $h(s^-(z_t), z_t)$ cuts the forty-five degree line at some point; let us denote by $\underline{z}$ the smallest steady state

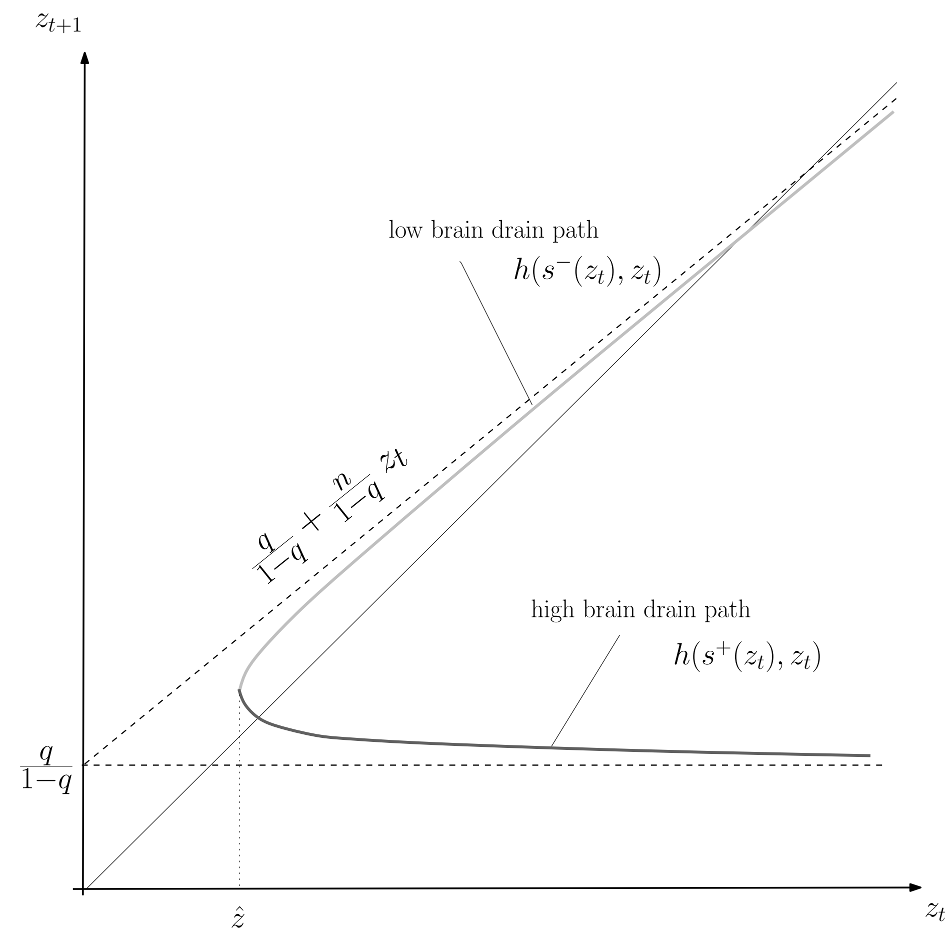

Figure 1: Dynamic correspondence

of the dynamics $z_{t+1} = h(s^-(z_t), z_t)$. Provided that $\bar{z}_0 \geq \underline{z}$, there exists at least one inter-temporal equilibrium (see De la Croix and Michel (2002), Proposition 3.6, for a similar case in the context of pension systems). ■

Obviously, as soon as one inter-temporal equilibrium exists, an infinite number of such equilibria exist.

The key condition separating the two cases of Proposition 1, $h(\hat{\varepsilon}, \hat{z}) > \hat{z}$, can be expressed explicitly as a condition on the productivity parameter A in the case where the function $G(\varepsilon)$ is a Gumbel distribution, which is a common assumption in endogenous migration models given the nice mathematical properties of that distribution:

$$G(\varepsilon) = 1 - e^{-e^{\frac{\varepsilon - m}{b}}}. \tag{9}$$

Using this functional form for $G()$, we can solve the inequality $h(\hat{\varepsilon},\hat{z}) < \hat{z}$ for the parameter A:

$$A < \left(\frac{\bar{A}^{\frac{1}{\alpha}} e^{-\frac{m}{\alpha}} \left(e^{b/\alpha}(1-q) - n \right) \left(\frac{b}{\alpha}\right)^{-\frac{b}{\alpha}}}{q} \right)^{\alpha} \Leftrightarrow h(\hat{\varepsilon},\hat{z}) < \hat{z}$$

Hence, the non-existence of equilibrium can only arise when productivity is small enough, given the other parameters.

We now derive some comparative static results in the context of a Gumbel distribution of migration costs. Results can be obtained for the point $p = \{\hat{z}, h(\hat{\varepsilon},\hat{z})\}$:

$$\hat{z} = \Phi \left(\frac{b}{\alpha}\right)^{-b/\alpha} e^{(b-m)/\alpha},$$

and $\hat{\varepsilon} = m + b \ln\left(\frac{b}{\alpha}\right)$. We first compute $h(\hat{\varepsilon},\hat{z})$ which gives:

$$h(\hat{\varepsilon},\hat{z}) = \frac{q}{1-q} + \frac{n}{1-q}\Phi\left(\frac{b}{\alpha}\right)^{-b/\alpha} e^{-m/\alpha}.$$

Using the partial derivatives of $\hat{z}$ and $h(\hat{\varepsilon},\hat{z})$ with respect to the parameters of interest, q, n, m, and Φ we get:

$$\frac{\partial p}{\partial q} = \left\{ 0, \frac{e^{-\frac{m}{\alpha}} n \Phi \left(\frac{b}{\alpha}\right)^{-\frac{b}{\alpha}} + 1}{(1-q)^2} \right\} \tag{10}$$

$$\frac{\partial p}{\partial n} = \left\{ 0, \frac{e^{-\frac{m}{\alpha}} \left(\frac{b}{\alpha}\right)^{-\frac{b}{\alpha}} \Phi}{1-q} \right\} \tag{11}$$

$$\frac{\partial p}{\partial m} = \left\{ -\frac{e^{\frac{-\log\left(\frac{b}{\alpha}\right)b+b-m}{\alpha}}\Phi}{\alpha}, -\frac{e^{-\frac{m}{\alpha}} n \left(\frac{b}{\alpha}\right)^{-\frac{b}{\alpha}} \Phi}{(1-q)\alpha} \right\} \tag{12}$$

$$\frac{\partial p}{\partial \Phi} = \left\{ e^{\frac{-\log\left(\frac{b}{\alpha}\right)b+b-m}{\alpha}}, \frac{e^{-\frac{m}{\alpha}} n \left(\frac{b}{\alpha}\right)^{-\frac{b}{\alpha}}}{1-q} \right\}. \tag{13}$$

Equations (10) and (11) indicate that, when q or n increases, the point p moves vertically upward. The conditions for existence would be unchanged in the case where $h(\hat{\varepsilon},\hat{z}) > \hat{z}$ ($\hat{z}$ is unchanged) or easier to fulfil in the case where $h(\hat{\varepsilon},\hat{z}) < \hat{z}$ as the smallest steady state $\underline{z}$ would be lowered. If the slope of the function does not change too much (which is what simulations indicate), it would also imply that the high steady state would be higher. This implies that education policies and/or population policies increasing n make the good stationary equilibrium better.

Equations (12) and (13) show that increasing location m or decreasing Φ (i.e. increasing productivity A) move the point p unambiguously to the South-West. Hence it enlarges the scope for the existence of equilibria ($\hat{z}$ is lower).

Remark on Trembling-Hand Perfection

When multiplicity occurs in static Nash equilibria, it is very common to question the "stability" of these equilibria. Although this notion of stability is sometimes judged dynamically naive (see Varian, 1992, p288),[5] it can be used as a tool to restrict the set of admissible Nash equilibria. An interesting notion proposed by Selten (1975) is that of the trembling-hand perfect Nash equilibrium, which selects Nash equilibria which are robust to the possibility that some players may make small mistakes. In order to apply this notion to our case, we draw the costs and benefits of migration, as a function of the migration rate. Letting migration g vary, the utility cost of the marginal person is $G^{-1}(g)$. The benefit from migration is, from Equation (6),

$$f(\varepsilon, z) = \ln \bar{A} - \ln A\left[(1-g))\, z\right]^{\alpha}$$

Figure 2 plots the two functions. The concave-convex black curve is the cost $G^{-1}(g)$. The grey curve is the benefit. It is a convex function of migration because home productivity and wages are a concave function of the skill ratio. Under Assumptions 1 and 2, these curves intersect twice, because Equation (6) has two roots. Let us now assess the trembling-hand perfection of these two Nash equilibria. Consider first the equilibrium on the left, which is the one with low poverty and low brain drain. Suppose that somebody made a mistake and that, for example, the person with a migration cost just above the threshold level ε migrated. As the grey curve is quite flat in that region, this move has only a slight positive effect on the relative gain of migration, through depressing local income via the externality. For him/her and the others with a higher ε_i, the cost (in black) is still higher than the benefit (in grey), and nobody moves. This equilibrium is trembling-hand perfect. Consider now the equilibrium on the right, the one with high poverty and high brain drain. If there is, by mistake, an additional migrant, we see that the benefit increases very sharply (the grey curve increases very fast at that point). This is because the economy is already poor in skilled persons, and so the marginal loss of an additional skilled worker is high. Then,

[5] This is probably why Acemoglu (1995), among others, does not use a stability criterion to discriminate between static equilibria, but introduces the notion of stability only when he proposes a truly dynamic extension of his model.

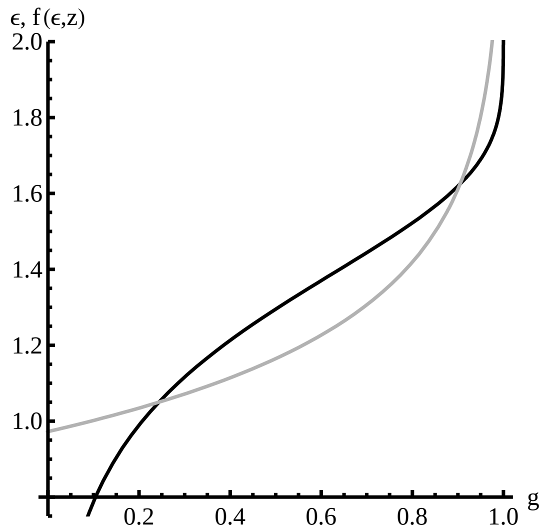

Figure 2: Nash equilibria

for households with a higher ε_i, there is a gain in moving too. This equilibrium is not trembling-hand perfect.

Although such arguments are often used to select a unique Nash equilibrium, let us stress that they are not very robust. To illustrate this point, let us modify the externality we assumed in Equation (2). Instead of following Lucas (1988), let us adopt Azariadis and Drazen's (1990) view that there are threshold externalities in technology. Having a skill ratio above a certain threshold allows access to better technologies. λ_t would then be a step function of k_t: there would be a partition $\{t_0, t_1, ...t_n\}$ of $\mathbb{R}_+$ representing the different thresholds, such that the function is constant on each (t_{i-1}, t_i). This case is represented in Figure 3 where we have assumed a step function with many levels (considering Equation (2) as a smooth approximation of a true model with a step function). The equilibrium on the right is now trembling-hand perfect: if an agent deviates, this will neither affect the technology, nor the gain from migrating, as the grey curve is locally horizontal, and nobody else would deviate from this equilibrium.

A similar argument could be made on the basis of institutional choices rather than technology levels. If the skill ratio can buy a level of institutional development (affecting total factor productivity), equilibria are stable as long as agents strictly prefer the current regime to the alternatives. Then, any epsilon change in the environment should not perturb the equilibrium. These arguments show that it makes little sense to put too much weight on the refinement of the Nash equilibria in our context, as any result could easily be overturned by slightly changing the technology.

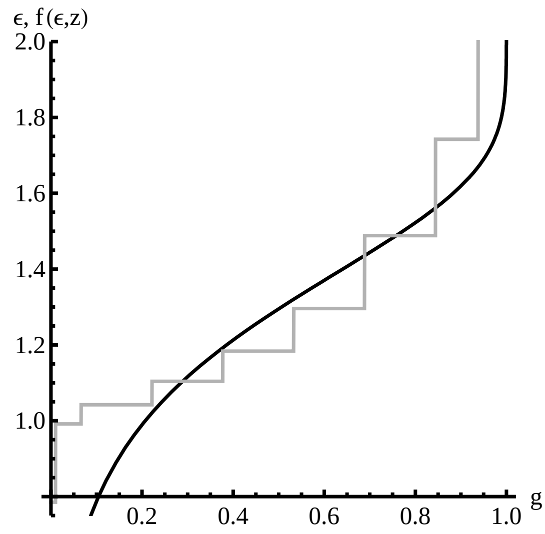

Figure 3: Nash equilibria with threshold externalities

3 Quantitative assessment

The goal of this section is to calibrate common and country-specific parameters, to draw the dynamic correspondence for each developing country, and to determine whether the observed situation corresponds to the high or the low brain-drain path. We use data on highly skilled emigration stocks/rates and on the labor force by education level as shown in the Appendix (available upon request). Three levels of education are distinguished, individuals with upper-secondary education, those with less than upper-secondary, and those with post-secondary education. High-skill workers are defined as those in the last category. Data on GDP are from the Penn World Tables. Our calibration is based on the year 2000 and is summarized in Table 1.

Table 1: Calibrated parameters - summary

Prm.	Definition	Source	Value
Global parameters			
α	Elasticity of productivity to human cap	Regressions 1990-2000	0.277
$\overline{A}$	Productivity in developed countries	Mean of 9 main dest	64.2
n	Fertility differential (as a ratio)	Kremer & Chen (1999)	0.605
Developing countries specific parameters			
A	Technological fixed effect	Equation (16)	
q	Prop of educ. children in low-skill hous.	Equation (17)	
m	Location of the mig. cost distrib.	Equation (19)	
b	Scale of the mig. cost distrib	Equation (18)	

3.1 Calibration of common parameters

Remember that parameters $\alpha \in (0,1)$ (the elasticity of productivity to the skill-ratio), $\bar{A} > 0$ (productivity in leading countries), and $n \in (0,1)$ (the fertility differential between high-skill and low-skill workers) are assumed to be identical in all developing countries.

To calibrate α, we regress $\ln \lambda_{j,t}$ on $\ln k_{j,t}$. Data on the labor force by education level are used to compute $k_{j,t}$. The numbers of high-skill, low-skill and medium-skill resident workers $(H_{j,t}, L^1_{j,t}, L^2_{j,t})$ are available for each country j from Docquier, Lowell and Marfouk's database for 1990 and 2000. High-skill workers $(H_{j,t})$ are those with post-secondary education. In the low-skill group, we distinguish workers with upper secondary education $(L^1_{j,t})$ and those with less than upper secondary $(L^2_{j,t})$. The skill-ratio in the resident labor force is given by

$$k_{j,t} = \frac{H_{j,t}}{L^1_{j,t} + L^2_{j,t}} \tag{14}$$

To compute $\lambda_{j,t}$, we use Equation (1) given estimates of the relative productivity of low-skill and medium-skill workers, ω^1 and ω^2. In a sample including many developing countries, Rosenzweig (2007, 2008) estimated an average return to schooling of between 7 and 10 percent per year. Considering that high-skill workers have 15 more years of schooling than the low skilled and 6 more years than the medium skilled, this gives $0.21 < \omega_1 < 0.34$ and $0.56 < \omega_2 < 0.67$. In our simulations, we use $\omega_1 = 0.25$ and $\omega_2 = 0.60$. Given GDP data, the productivity scale factor of country j is obtained as a residual:

$$\lambda_{j,t} = \frac{Y_{j,t}}{\omega^1 L^1_{j,t} + \omega^2 L^2_{j,t} + H_{j,t}}. \tag{15}$$

We use data for 1990 and 2000, and normalize γ^{00} to unity and $\gamma^{90} = \overline{A}_{90}/\overline{A}_{00}$ in Equation (2). Regressing $\ln \lambda_{j,t}/\gamma^t$ on $\ln k_{j,t}$ gives an estimate for α. Using a large sample of developing countries (142 observations), we obtain an elasticity of 0.277, significant at 1 percent (the R-squared of the regression is 0.24). This elasticity will be used in the benchmark simulation. Using a larger sample of 195 developing and developed countries, we obtain an elasticity of 0.447 (the R-squared is 0.38). This larger value will be used in the robustness analysis.

The calibrated productivity in leading countries, $\bar{A}$, is the weighted average of the productivity scale factors obtained from (15) for 9 major destination countries (Australia, Canada, France, Germany, Japan, Korea, Saudi Arabia, the United Kingdom and the United States). The weights are the country's shares in the total labor force of the group. We obtain $\bar{A} = 64.18$.

Using data from Kremer and Chen (1999), we compute the differential fertility for 1985-89 for 26 developing countries (to our knowledge there is no broader set of data on differential fertility than this one). The correlation between country-specific fertility differentials and the human capital of women is low (14 percent) so that we can consider the fertility differential as independent of the level of development. The average fertility differential between high-skill (more than 10 years of education) and low-skill workers (less than 10 years of schooling) amounts to 0.605. We use this value for n in all countries.

3.2 Calibration of country-specific characteristics

As stated in Definition 1, each developing country j is characterized by a quadruple of parameters $\Omega_j = \{A_j, q_j, m_j, b_j\}$ representing the technological fixed effect ($A_j > 0$), the fraction of educated children in low-skill households ($q_j \in (0,1)$), the location and the scale parameters of the distribution of migration cost ($m_j \in \mathbb{R}$,$b_j > 0$).

The calibration of the technological fixed effect A_j is done at the year 2000. Using Equation (2) and the estimated value for α, we have:

$$\ln A_j = \ln \lambda_{2000,j} - 0.277 \times \ln k_{2000,j} \tag{16}$$

where $k_{2000,j}$ and $\lambda_{2000,j}$ are given by Equations (14) and (15).

To calibrate q_j, we use the dynamic equation (5) and consider that one period represents 25 years. The proportion of high-skill workers in the resident labor force (*ex post* or after-migration labor force), $k_{j,75}$, can be obtained for 1975 from Defoort (2008), herself relying on different sources (mostly Barro and Lee, 2000). The proportion of high-skill workers in the native labor force (*ex ante* or before-migration labor force), $z_{j,00}$, can be obtained for 2000 by adding resident and emigrant workers by education level and computing the structure of the native labor force. Data on human capital and emigrants to OECD destinations in 2000 are taken from Docquier, Lowell and Marfouk (2009). Generally speaking, the skill level of immigrants to non-OECD countries is expected to be very low, except in a few countries such as South Africa, the member states of the Gulf Cooperation Council, and some East Asian countries such as Singapore or Hong Kong. Focusing on OECD destinations, the database should capture a large fraction of worldwide educated migration (between 80 and 90 percent), but is also likely to underestimate the number of emigrants from developing countries located in the neighborhood of important destinations. Here, we have collected or estimated data from non-OECD destinations to expand the coverage of previous studies. We double the number of destinations, adding 31 non-OECD destinations, compute more accurate measures of the brain drain for all the world countries, and characterize "South-South" and "North-South" emigration patterns. As expected, the inclusion of non-OECD countries such as the Gulf states, South Africa, and Singapore has a impact on the brain drain of neighboring countries. Our method is explained in an Appendix. Equation (5) can be rewritten as

$$z_{j,00} = \frac{nk_{j,75}}{1-q_j} + \frac{q_j}{1-q_j}.$$

Solving for q_j yields:

$$q_j = \frac{z_{j,00} - nk_{j,75}}{1+z_{j,00}}. \tag{17}$$

For all countries excepted Saint Kitts and Nevis ($q = 0.4574$), we have $q < 1-n$ so that the oblique asymptote on Figure 1 has a slope lower than one.

Finally, we have to specify a functional form for the distribution of migration costs and estimate its parameters. In the benchmark analysis, migration costs are assumed to follow a Gumbel distribution with country-specific parameters $m \in \mathbb{R}$ (location) and $b > 0$ (scale). The mean and variance of the distribution is related to the location and scale parameters as follows: mean $= m - \gamma b$ where γ is Euler's constant (0.577), and variance $= \pi^2 b^2/6$. Inverting $G(\varepsilon)$ gives $\frac{\varepsilon_j - m_j}{b_j} = G^{-1}(G_j) = \ln\left[-\ln(1-G_j)\right]$. The Gumbel distribution is a continuous probability distribution belonging to the family of generalized extreme value distributions. It is traditionally used in migration models where utility includes an iid random component varying between individuals and countries of destination (see Grogger and Hanson, 2008).[6] The logistic or normal distributions will be used in the robustness analysis.

Since this function has two country-specific parameters, we need two observations to calibrate them. For each developing country, we can compute $\varepsilon_j \equiv \ln \bar{A} - \ln A - \alpha \ln k_j$ and observe G_j in 2000. This gives a first pair(ε_j, G_j) which can be used to identify the parameters of the distribution. We need another reference pair $(\varepsilon_{\min}, G_{\min})$ to characterize the hypothetical brain drain rate $G_{\min}$ obtained with low poverty level $\varepsilon_{\min}$. In the benchmark analysis, we assume that at the level of the US income (ε_{US}), the brain drain of each developing country would equal the US brain drain (G_{US}). This allows us to calibrate (m_j, b_j) as:

$$b_j = \frac{\varepsilon_j - \varepsilon_{US}}{G^{-1}(G_j) - G^{-1}(G_{US})} \tag{18}$$

$$m_j \equiv \varepsilon_j - b_j \times G^{-1}(G_j). \tag{19}$$

The coefficients (m_j, b_j) capture the mean of migration costs and the average sensitivity of

[6] As shown by McFadden (1984), when the iid component follows an extreme value distribution, the probability that an individual emigrates to a particular destination is governed by a simple logit expression.

migration to income differentials. Given (18) and (19), m_j and b_j are perfectly collinear. The recent empirical literature on international migration reveals that the propensity to emigrate is a function of the distance to OECD countries, language spoken, country size and cultural links with potential destinations, etc. A simple correlation analysis reveals that m_j (and hence b_j) is positively correlated with population size (0.32) and distance to OECD (0.20), and negatively correlated with dummies capturing former colonial ties (-0.43), knowledge of English (-0.26) and being an oil producing country (-0.10).

Consequently, the mean of the distribution is low in small states and small islands, and in regions such as Central America and the Caribbean, Northern and Southern Africa, the new members of the European Union and countries located in the neighborhood of the Persian Gulf states. On the contrary, m_j is higher in the ex-Soviet block, in South-East and East Asia, in many countries of South America, and Central Africa.

3.3 Benchmark configurations

The calibration of country-specific parameters allows us to draw the dynamic correspondence (8) for each developing country, to compute steady state equilibria and check their stability, and to compare the observed equilibrium path to the alternative one when multiplicity occurs. Our numerical exercise was conducted on 147 developing countries and gave the following results.

All countries except Croatia and Saint Kitts and Nevis are characterized by 2 locally stable steady state equilibria, the "low-brain-drain" steady state equilibrium (z^-, G^-) and the "high-brain-drain" steady state equilibrium (z^+, G^+).[7] Figure 3.3 represents the dynamic correspondence for two countries, Guatemala, and Trinidad and Tobago. In Guatemala, the observed dynamics lie on the upper part of the correspondence, i.e. on the low-brain-drain dynamics. If they stay on the same path, the dynamics will converge monotonically to a steady state, at the intersection of this path with the 45-degree line. In Trinidad and Tobago, the observed dynamics lie on the lower part of the correspondence, i.e. on the high-brain-drain dynamics. If they stay on the same path, the dynamics will converge with damped oscillations to a steady state. At each date, another path with lower brain drain is possible, though.

Large countries exhibit high migration costs. Considering the 105 countries with more than 2 million inhabitants, the observed equilibrium in 2000 (z_{00}, G_{00}) is on the good path in

[7]In Croatia, (z^+, G^+) is unstable. As mentioned above, in Saint Kitts and Nevis the oblique asymptote on Figure 1 has a slope higher than one implying that the dynamics can be unbounded.

the vast majority of cases, as for Guatemala above. Only two cases are on the bad path. Jamaica exhibits a brain drain of 84.7 percent. Remaining on the bad path, its brain drain would reach 86.3 percent in 2025 and 86.2 percent at the steady state. Moving to the good path would reduce the long-run brain drain to 3.0 percent. Haiti exhibits a brain drain of 83.4 percent. Remaining on the bad path, its brain drain would reach 86.0 percent in 2025 and 85.8 percent at the steady state. Moving to the good path would reduce the long-run brain drain to 18.7 percent.

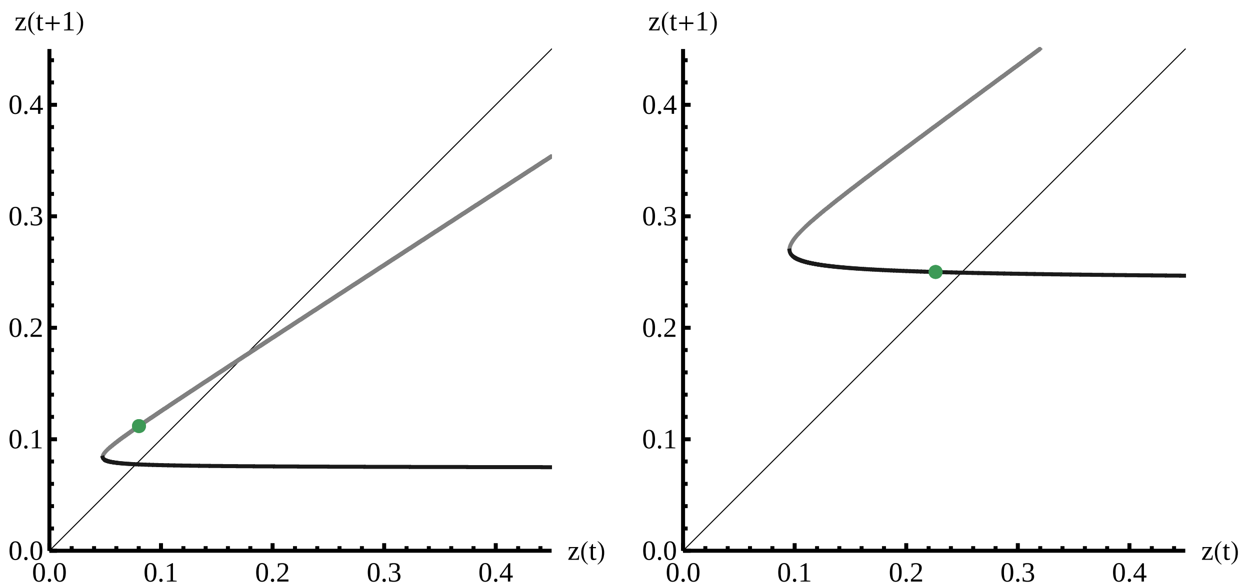

Figure 4: Correspondences for Guatemala (left), and Trinidad and Tobago (right)

The 103 other countries with population above 2 million are on the good path. The bad path is usually a trivial situation with more than 95 percent brain drain and high poverty. We have 14 exceptions for which the bad path involves a brain drain below 90 percent (See Table 2). In these countries, a major adverse shock could have damaging long-run effects on the economy if it gives rise to a sudden and uncoordinated emigration of the highly skilled. These are the Dominican Republic (5.5 vs 85.6 percent)[8], El Salvador (10.0 vs 83.6), Guatemala (10.0 vs 90.0), Lebanon (8.4 vs 75.0), Macedonia (20.4 vs 87.7) Malaysia (2.5 vs 72.3), Mexico (5.1 vs 89.6), Namibia (19.3 vs 82.6), Nicaragua (19.6 vs 89.1), Papua New Guinea (7.5 vs 80.8), Tunisia (4.7 vs 89.8), Uruguay (3.5 vs 79.2), the Czech Republic (2.9 vs 87.8) and Hungary.(3.7 vs 77.8).

In the 42 small states with less than 2 million inhabitants, the configuration is mixed. On the one hand, 22 small states are on the good path (z^-, G^-) in 2000. Table 3 lists these countries and gives their equilibrium in 2025 and at the steady state, provided that they remain on

[8]Numbers in parentheses are G^-_{ss} and G^+_{ss} in percent for the 14 countries.

Table 2: Large states at risk of coordination failure

Country	z_{00}^-	G_{00}^-	z_{25}^-	G_{25}^-	z_{ss}^-	G_{ss}^-	z_{ss}^+	G_{ss}^+
Czech Republic	0.133	0.090	0.181	0.056	0.283	0.029	0.109	0.878
Dominican Republic	0.219	0.227	0.320	0.131	0.629	0.055	0.221	0.856
El Salvador	0.176	0.323	0.243	0.204	0.434	0.100	0.181	0.836
Guatemala	0.080	0.244	0.112	0.164	0.174	0.100	0.078	0.899
Hungary	0.158	0.134	0.210	0.081	0.336	0.037	0.138	0.778
Lebanon	0.214	0.455	0.283	0.248	0.591	0.084	0.242	0.750
Macedonia	0.236	0.320	0.277	0.272	0.373	0.204	0.180	0.877
Malaysia	0.098	0.174	0.141	0.075	0.244	0.025	0.107	0.723
Mexico	0.150	0.156	0.213	0.098	0.360	0.051	0.137	0.896
Namibia	0.059	0.294	0.068	0.248	0.085	0.193	0.047	0.826
Nicaragua	0.145	0.324	0.177	0.264	0.241	0.196	0.120	0.891
Papua New Guinea	0.021	0.289	0.030	0.153	0.049	0.074	0.024	0.808
Tunisia	0.074	0.143	0.107	0.086	0.171	0.047	0.071	0.898
Uruguay	0.163	0.120	0.214	0.075	0.336	0.035	0.136	0.792

the good path. Except in the Solomon Islands, the brain drain is expected to decrease in these countries; the average emigration rate in this group amounts to 29.6 percent in 2000 and will fall to 18.3 percent in the long-run (23.0 percent in 2025). The alternative brain drain rate is below 90 percent in 11 countries which face substantial risks of coordination failure. On the other hand, 20 small states are on the bad path (z^+, G^+) in 2000. Table 4 shows that the emigration rate will increase in all these countries; the average rate equals 69.5 percent in 2000 and will reach 75.9 percent in the long-run (76.9 percent in 2025).

For other countries with populations above 2 million, we predict a significant decrease in the brain drain, provided that they remain on the same branch of the dynamic path. Exceptions are Jamaica and Haiti (on the bad path), Pakistan and Nigeria. The average emigration rate is equal to 19.1 percent in 2000. It will fall to 15.5 percent in 2025 and 12.6 percent in the long-run.

In sum, according to our model, 22 countries (including 20 small states, Jamaica and Haiti) are suffering from a coordination failure. By repatriating highly skilled natives working abroad, they would reach a productivity level sufficient to encourage high-skill workers to stay and generating more human capital accumulation. This represents 15 percent of the sample, but 47.6 percent of countries with less than 2 million inhabitants. Hence, coordination failure leading to massive high-skill emigration is an important problem when migration costs are low. In 25 other cases, the risk of a coordination failure is high.

Table 3: Small states on the good path

Country	z^-_{00}	G^-_{00}	z^-_{25}	G^-_{25}	z^-_{ss}	G^-_{ss}	z^+_{ss}	G^+_{ss}
Bahamas	0.338	0.259	0.507	0.043	1.474	0.002	0.441	0.622
Botswana	0.045	0.084	0.068	0.050	0.108	0.028	0.043	0.948
Comoros	0.026	0.231	0.035	0.195	0.048	0.165	0.023	0.997
Djibouti	0.058	0.039	0.080	0.034	0.117	0.028	0.045	1.000
East Timor	0.065	0.222	0.082	0.203	0.104	0.185	0.050	1.000
Equatorial Guinea	0.053	0.220	0.076	0.067	0.133	0.017	0.064	0.650
Estonia	0.278	0.111	0.419	0.066	0.858	0.027	0.248	0.925
Gabon	0.143	0.049	0.224	0.026	0.404	0.012	0.135	0.953
Gambia	0.013	0.682	0.013	0.650	0.014	0.612	0.012	0.857
Guinea-Bissau	0.014	0.289	0.018	0.260	0.023	0.237	0.012	1.000
Kiribati	0.034	0.558	0.039	0.479	0.048	0.403	0.032	0.885
Lesotho	0.014	0.248	0.019	0.197	0.027	0.159	0.013	0.991
Marshall Islands	0.135	0.429	0.163	0.355	0.218	0.271	0.121	0.882
Micronesia	0.148	0.487	0.176	0.376	0.258	0.240	0.146	0.788
Namibia	0.059	0.294	0.068	0.248	0.085	0.193	0.047	0.826
Nauru	0.053	0.721	0.059	0.604	0.074	0.475	0.055	0.835
Sao Tome and Principe	0.043	0.275	0.060	0.228	0.083	0.192	0.041	0.997
Slovenia	0.191	0.126	0.234	0.044	0.372	0.007	0.199	0.426
Solomon Islands	0.020	0.260	0.019	0.271	0.018	0.288	0.010	0.941
Swaziland	0.055	0.195	0.080	0.061	0.140	0.016	0.066	0.673
Tuvalu	0.043	0.652	0.048	0.539	0.062	0.415	0.044	0.824
Vanuatu	0.084	0.084	0.111	0.073	0.154	0.063	0.061	1.000

4 Robustness

In this section, we analyze the robustness of our results to the identifying strategy and to the brain-gain mechanism, which implies the endogeneity of q_j.

4.1 Robustness to identifying assumptions

Our benchmark numerical exercise is based on three major identifying assumptions:

- The elasticity of productivity to human capital is estimated on a sample of developing countries. We obtained $\underline{\alpha}= 0.277$. Using the full sample of 195 countries, the elasticity goes up to $\overline{\alpha} = 0.447$. A priori, a higher α can reinforce the possibility of multiple equilibria since it increases the sensitivity of economic performances to high-skill emigration.

Table 4: Small states on the bad path

Country	z_{00}^{+}	G_{00}^{+}	z_{25}^{+}	G_{25}^{+}	z_{ss}^{+}	G_{ss}^{+}	z_{ss}^{-}	G_{ss}^{-}
Antigua and Barbuda	0.457	0.704	0.553	0.781	0.541	0.774	3.258	0.002
Barbados	0.363	0.627	0.460	0.727	0.453	0.721	1.907	0.000
Belize	0.284	0.656	0.345	0.753	0.336	0.743	1.128	0.009
Cape Verde	0.059	0.828	0.065	0.849	0.065	0.848	0.161	0.007
Cyprus	0.318	0.353	0.399	0.502	0.394	0.494	NA	0.000
Dominica	0.471	0.641	0.608	0.755	0.591	0.746	3.885	0.000
Fiji	0.206	0.628	0.236	0.775	0.223	0.738	0.466	0.145
Grenada	0.611	0.843	0.682	0.865	0.679	0.864	15.495	0.000
Guyana	0.388	0.894	0.413	0.904	0.411	0.904	1.966	0.032
Malta	0.168	0.585	0.193	0.630	0.193	0.641	NA	0.000
Mauritius	0.091	0.419	0.115	0.579	0.113	0.567	0.233	0.000
Palau	0.258	0.838	0.285	0.850	0.285	0.854	NA	0.000
Saint Kitts & Nevis	0.866	0.844	0.994	0.866	0.991	0.866	∞	0.000
Saint Lucia	0.152	0.687	0.164	0.736	0.162	0.729	0.377	0.050
Saint Vinc & Grenadines	0.309	0.846	0.326	0.857	0.325	0.856	1.291	0.004
Samoa	0.291	0.735	0.323	0.814	0.313	0.796	0.722	0.171
Seychelles	0.187	0.572	0.235	0.688	0.231	0.680	0.619	0.000
Suriname	0.271	0.660	0.320	0.759	0.310	0.745	0.933	0.032
Tonga	0.313	0.757	0.346	0.815	0.338	0.804	0.897	0.125
Trinidad and Tobago	0.226	0.790	0.250	0.814	0.249	0.813	0.812	0.000

- Individual migration costs are assumed to follow a Gumbel cumulative distribution function. In this section, we consider two other distributions characterized by two location and dispersion parameters, the logistic and the normal distributions.

- The identification of the parameters of the migration costs' distribution relies on the hypothesis that at the US income level ($\varepsilon_{US} = -0.013$), developing countries would have the same brain drain as the US (i.e. $G_{US} = 0.005$). Since most cases of coordination failure occur for small states, the minimal brain drain of these countries may be expected to exceed the US level at high income. In this section, we identify the parameters of the distribution on the Qatar income and brain-drain levels ($\varepsilon_{Qat} = -0.382$ and $G_{Qat} = 0.023$), Qatar being a small state with about 745,000 inhabitants according to our definition.

In Table 5, we identify the cases of coordination failures in 12 scenarios: 2 values for α $\times$ 3 distributions $\times$ 2 values for $(\varepsilon_{\min}, G_{\min})$. Unsurprisingly, the number of coordination failures increases when $\overline{\alpha} = 0.447$, and decreases when the parameters of the migration costs' distribution are calibrated on Qatar. The use of the normal distribution (and logistic to a lesser extent) also reduces the number of countries on the bad path.

For 7 countries, a coordination failure is obtained in all scenarios. These are Cape Verde, Grenada, Palau, St Kitts and Nevis, St Vincent and Grenadines, Malta, and Trinidad and Tobago. For 7 other countries, a coordination default is obtained under 10 scenarios: Belize, Dominica, Guyana, Jamaica, Seychelles, Antigua and Barbuda, and Barbados. Mauritius and Cyprus are also robust cases.

4.2 Robustness to "brain gain" channel

As stated in the introduction, a wave of brain-drain research has emerged since the mid-1990s around the idea that highly skilled emigration generates positive feedback effects for sending countries. In particular, it has been demonstrated that high-skill migration prospects can foster domestic enrolment in education in developing countries, raising the possibility of the brain drain being beneficial to the source country (Mountford, 1997; Stark et al., 1998; Beine et al., 2001, 2008).

This "brain gain" hypothesis can be introduced into our model by endogenizing q_j as a function of the current emigration rate. In line with the recent "brain gain" literature, a simple regression of identified q_j (obtained from (17)) on observed high-skill emigration rates G_j shows a positive and highly significant relationship (p-value below 1 percent). We have $q_j = C + 0.095\ G_j + \eta_j$ where C is the intercept and η_j is a error term. Defining $q_{0,j} \equiv C + \eta_j$ as a country-specific constant, we obtain an identified model matching observations and compatible with the brain gain view. The brain gain variant is made of Equations (6) and (7) from Definition 2, and the training technology (subscript j is removed to be compatible with definition 2):

$$q = q_0 + 0.095\ G \equiv q(G). \tag{20}$$

Unlike the benchmark model, the long-run level of human capital k_{ss} is now an ambiguous function of the high-skill emigration rate G. To illustrate this, let us first treat G as an exogenous variable and characterize its effect on human capital accumulation. At the steady state, combining (4) and (5) gives

$$\begin{aligned} k_{ss} &= \frac{(1-G)\cdot q(G)}{1-q(G)-n(1-G)} \\ \frac{\partial k_{ss}}{\partial G} &= \frac{-q(G)\left[1-q(G)\right] + \frac{\partial q}{\partial G}(1-G)\left[1-n(1-G)\right]}{\left[1-q(G)-n(1-G)\right]^2}. \end{aligned}$$

Table 5: Robustness to identifying assumptions: x indicates a coordination failure case

Identification m,b	USA						Qatar						USA
G(.)	Gumbel		Logistic		Normal		Gumbel		Logistic		Normal		Gumbel
α	$\underline{\alpha}$	$\overline{\alpha}$	$\underline{\alpha}$	$\overline{\alpha}$	$\underline{\alpha}$	$\overline{\alpha}$	$\underline{\alpha}$	$\overline{\alpha}$	$\underline{\alpha}$	$\overline{\alpha}$	$\underline{\alpha}$	$\overline{\alpha}$	$\underline{\alpha}$
Brain gain	no	no	no	no	no	no	no	no	no	no	no	no	yes
Belize	x	x	x	x	x	x	x	x		x		x	x
Cape Verde	x	x	x	x	x	x	x	x	x	x	x	x	x
Dominica	x	x	x	x	x	x	x	x		x		x	x
Fiji	x	x		x		x		x					x
Gambia		x		x									
Grenada	x	x	x	x	x	x	x	x	x	x	x	x	x
Guyana	x	x	x	x	x	x	x	x		x		x	x
Haiti	x	x		x		x	x	x					x
Jamaica	x	x	x	x	x	x	x	x		x		x	x
Kiribati				x									
Lebanon		x		x									
Mauritius	x	x	x	x	x	x		x		x		x	x
Micronesia		x		x									
Nauru		x		x									
Palau	x	x	x	x	x	x	x	x	x	x	x	x	x
Saint Kitts & Nevis	x	x	x	x	x	x	x	x	x	x	x	x	x
Saint Lucia	x	x	x	x		x		x		x		x	x
Saint Vinc & Gren	x	x	x	x	x	x	x	x	x	x	x	x	x
Samoa	x	x		x		x		x					x
Seychelles	x	x	x	x	x	x	x	x		x		x	x
Suriname	x	x	x	x		x		x					x
Tonga	x	x		x		x		x					x
Tuvalu		x		x									
Antigua & Barbuda	x	x	x	x	x	x	x	x		x		x	x
Bahamas		x		x									
Barbados	x	x	x	x	x	x	x	x		x		x	x
Cyprus	x	x	x	x	x	x		x		x		x	x
Malta	x	x	x	x	x	x	x	x	x	x	x	x	x
Trinidad & Tobago	x	x	x	x	x	x	x	x	x	x	x	x	x
Coordination failure	22	28	18	29	16	22	15	22	7	17	7	17	22

Under the traditional view of the benchmark model, we have $\partial q/\partial G = 0$ and $\partial k_{ss}/\partial G < 0$, where $\partial q/\partial G > 0$, $\partial k_{ss}/\partial G$ can be positive or negative. In particular, the high-skill emigration rate maximizing the long-run level of residents' human capital is positive if $[\partial k_{ss}/\partial G]_{G=0} > 0$. This requires $0.095(1-n) > q_0(1-q_0)$ (i.e. $q_0 < 0.039$ since $n = 0.605$ in our calibration). This condition is very similar to that of Beine et al (2008). Such a situation is obtained in 64 developing countries (out of 147). More generally, the growth-maximizing high-skill emigration rate G^* is the solution of $\partial k_{ss}/\partial G = 0$; our numerical experiment reveals that G^* is a decreasing and non-linear function of q_0 which can be approximated by the linear function: $G^* = 0.411 - 10.12\, q_0$.

However, G is clearly endogenous and determined by our system (6)-(7)-(20). Solving this system for the 147 developing countries in our sample and provided that countries remain on the same path as in 2000, we can show that the long-run high-skill emigration rate resulting from utility maximization is lower than G^* in 57 cases (i.e. 38.8 percent of our sample). This result is obtained with the benchmark hypotheses: Gumbel distribution, identification of the parameters of the distribution of migration costs based on the US, and $\alpha = \underline{\alpha} = 0.277$.

The key question is: does the brain-gain channel modify the number of coordination failures? In the previous model disregarding the brain-gain channel, the low brain-drain equilibrium was always better than the high brain-drain solution in terms of economic performance at origin. Accounting for brain-gain effect, it is now theoretically possible that the high brain-drain equilibrium generates higher human capital and productivity at origin than the low brain-drain one.

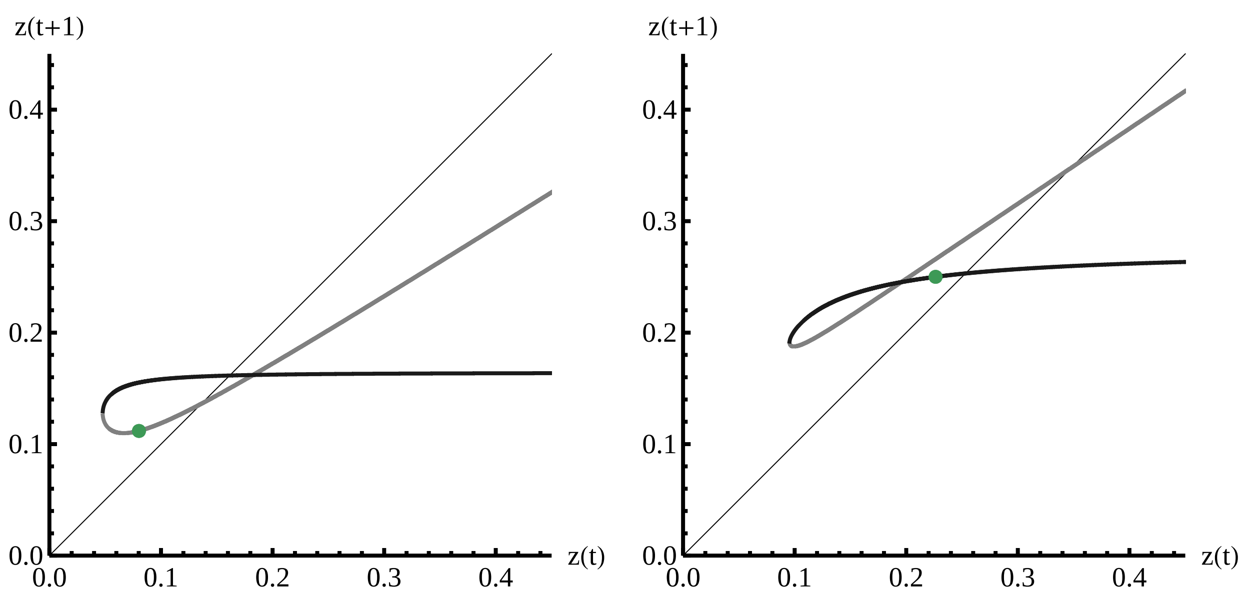

Figure 5: Correspondences for Guatemala and Trinidad and Tobago with brain-gain effect

However, our results do not support this possibility. Focusing on our two examples (Guatemala and Trinidad and Tobago), Figure 5 shows that the dynamic correspondence changes compared to the model with exogenous q_j (see Figure 3.3). For low levels of *ex ante* human capital z_t, the high brain-drain path (dark grey curve) is conducive to more *ex ante* human capital in the next period than the low brain-drain path (light grey curve). But the numerical results show that the high brain-drain path always corresponds to the case with low *ex post* human capital and high poverty.

Finally, the last column in Table 5 shows that the brain-gain channel does not modify the number of coordination failures compared to the benchmark scenario of the first column.

5 Conclusion

When skilled households expect their home country to have low productivity and to be poorly governed, the most mobile of them will move to a better place. This can only reinforce the bad features present at home. On the contrary, if people expect high productivity and good governance in their home country, they will usually stay at home, thereby promoting high productivity, good governance, and wealth accumulation.

Such vicious or virtuous circles seem to arise very naturally when one takes into account the relationship between brain drain and development level in the home country. We accordingly built a model which is open to the possibility of multiple equilibria. We derived theoretical conditions under which they effectively arise. Identifying country-specific parameters in the data, we classified countries into different categories depending on whether multiple equilibria are possible, and whether the observed situation might be one of high brain drain and high poverty.

In most countries, the observed equilibrium has higher income than the other possible equilibria. For 22 developing countries (20 small states, Jamaica and Haiti), poverty and high brain drain are worsened by a coordination failure. By repatriating highly skilled natives working abroad, they would reach a productivity level inciting high-skill workers to stay and generating more human capital accumulation. In 25 other countries following the low brain drain path, there exists a reasonable high brain-drain path involving higher emigration rates and increased poverty. In these countries, a major adverse shock could have damaging long-run effects on the economy if it gives rise to a sudden emigration of the highly skilled.

6 References

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